Reducing CO_2 from Fossil Fuels

Input for Tri-State Generation & Transmission Association

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(Submitted in advance)

Clean Air Task Force is a non-profit organization dedicated to reducing atmospheric pollution through research, advocacy, and private sector collaboration.

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Examples of CATF approach

- Work extensively with dozens of developers of new gasification projects with CCS to understand the barriers they face.
- Conducted extensive interviews with PCC project developers, technology vendors, and engineering, procurement and construction (EPC) contractors to identify the technology and financial barriers that face pioneer PCC projects.
- Hired NorthBridge Group for dispatch modeling on each coal unit in the Eastern Untied States to assess retrofit policies and retirements.
- Hired Keybridge Research LLC to understand jobs and economic impacts of CCS.
- Published “Coal without Carbon” an RD&D blueprint for federal CCS investment authored by researchers at MIT, Tufts, and Lawrence Livermore National Labs.
- Extensive outreach in China to create US-Chinese business partnerships aimed at reducing technology cost.

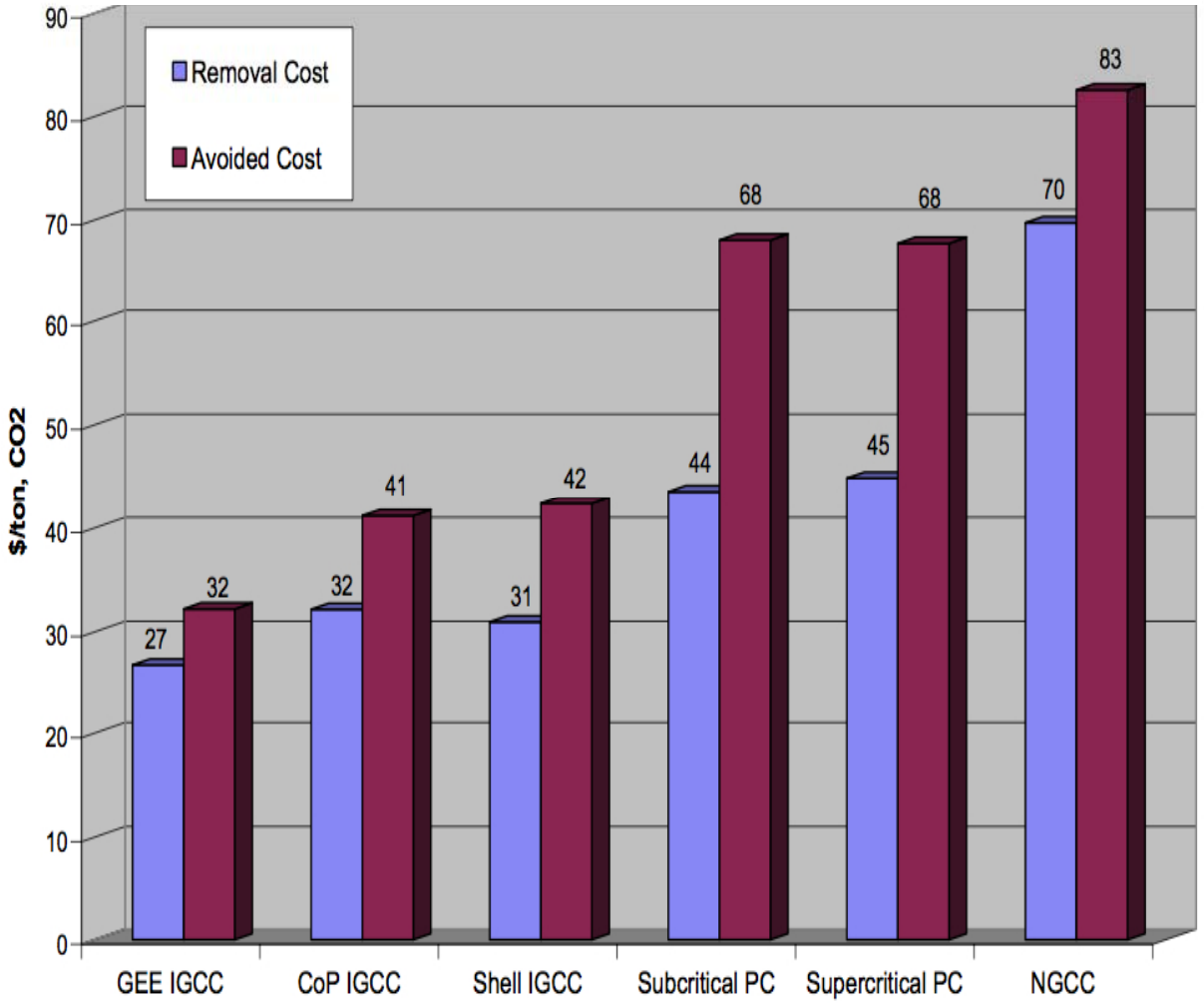
Summary

- Like much of the rest of the world, Tri-State's electricity generation is dominated by fossil fuel combustion (70% by coal)
- Achieving full reductions in CO2 emissions from Tri-State's fleet will therefore almost certainly require carbon capture and sequestration ("CCS") technology both for existing units and perhaps for new units yet to be added by Tri-State and its partners
- Three approaches to CCS could be especially important for Tri-State going forward
  - Inclusion of CCS on new natural gas-fired units
  - Retrofit of CCS to Tri-State's existing coal-fired units
  - New and retrofit gas units based on underground coal gasification with CCS
- Some CCS technology could be deployed synergistically with intermittent renewable resources (e.g., wind) in Tri-State's system

CCS cost metric #1: cost to reduce CO2

- By one conventional metric ($ per ton) IGCC with CCS is more cost-effective than natural gas combined cycle ("NGCC") with CCS
- But if the metric is electricity cost to consumers, the results can be different, as indicated in the next slide

Costs of coal and natural gas with 90% CO2 capture

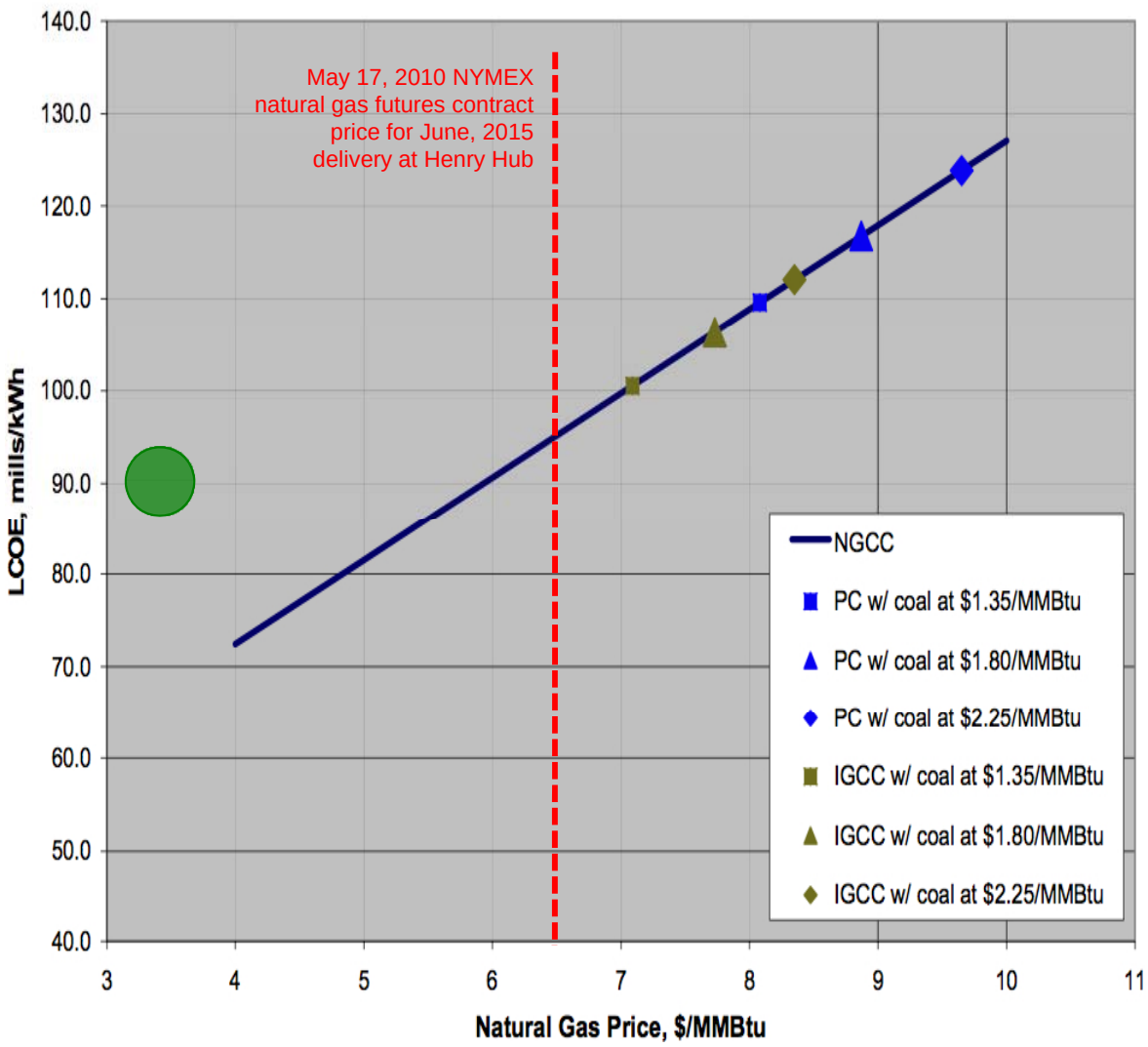


Data source: DOE/NETL, Cost and Performance Baseline for Fossil Energy Plants, 2007, ES-11.

CCS cost metric #2: cost of electricity

- For low natural gas prices, NGCC with CCS could produce power for less cost than new coal with CCS, as indicated in the figure at right
- CO2 emissions from a new NGCC with CCS would be about 5% of those from existing coal plants
  - 93 lb/MWh-net for NGCC+CCS
  - ~2000 lb/MWh-net for PC
- ("UCG" placeholder, in green, discussed in following slides)

Costs of coal and natural gas with 90% CO2 capture



Data source: DOE/NETL, Cost and Performance Baseline for Fossil Energy Plants, 2007, ES-9.

CO2 capture on NGCC is available today

- Example: Bellingham, MA NGCC with CO2 capture
  - 320 MWe combined cycle turbines burning natural gas
  - 15% of flue gas is diverted to a CO2 removal unit based on Fluor "Econamine"
    - 85% - 95% CO2 removal
    - 350 tons/day
    - Equivalent to ~50MWe
    - Used for beverages
    - First commercial operations 1991 (capture ceased 2005)
- A number of vendors have significant experience with CO2 capture from natural gas combustion

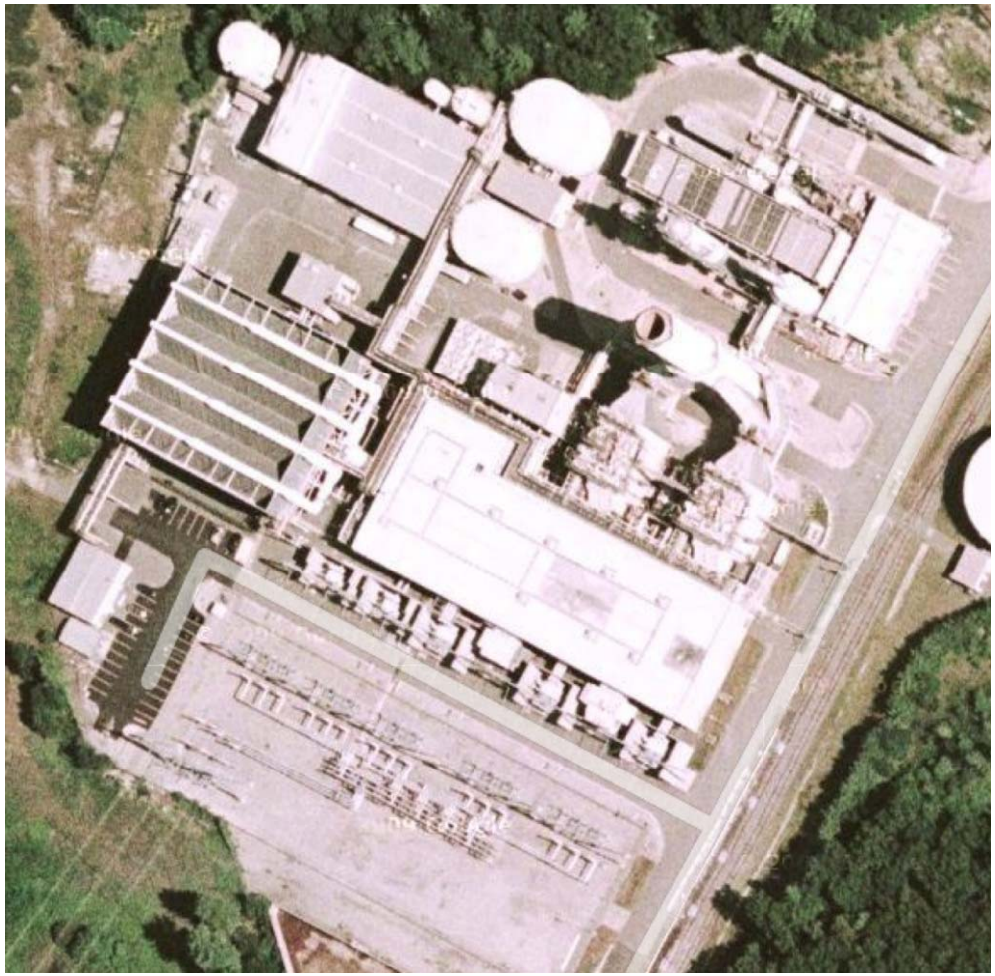


Image Source: Google

Data source: http://www.co2captureandstorage.info/project_specific.php?project_id=29

But whither future natural gas prices?

- Although low now, future natural gas prices could be high, even for unconventional (e.g., shale) gas

"A couple of weeks ago, I quoted Ben Dell, an analyst with Bernstein Research in New York, as **estimating the shale gas industry really needs a price of $7.50 to $8 to break even on its all-in costs** of finding and producing the stuff, which would be a 60 per cent price rise. Not easy for many people, or industries, to pay these days.

More people have written to me on this than on any other topic over the past year. Skeptics egg me on. Industry advocates forward consultants' studies talking of "learning curves" and $5 gas as far as the eye can see. Not many neutrals.

So I worked people in the energy service industry, and gas producers to try and refute Ben Dell's numbers. I couldn't. **My industry sources' numbers all converged close to $8 per mcf**."

- John Dizard, Financial Times (London), March 21, 2010 (emphasis added)

- This suggests that for base-load power, coal could stay in the mix for quite some time

UCG: Coal CCS outside the box

- UCG is the gasification of coal deep underground
  - Air or oxygen and steam are injected into a deep, wet coal seam
  - Chemical reactions produce ‘syngas’
  - Syngas is brought to surface using a separate well
- It’s *below* the water table
  - No risk of a “runaway fire”
  - But protecting groundwater from contamination is key
  - Good site selection is vital

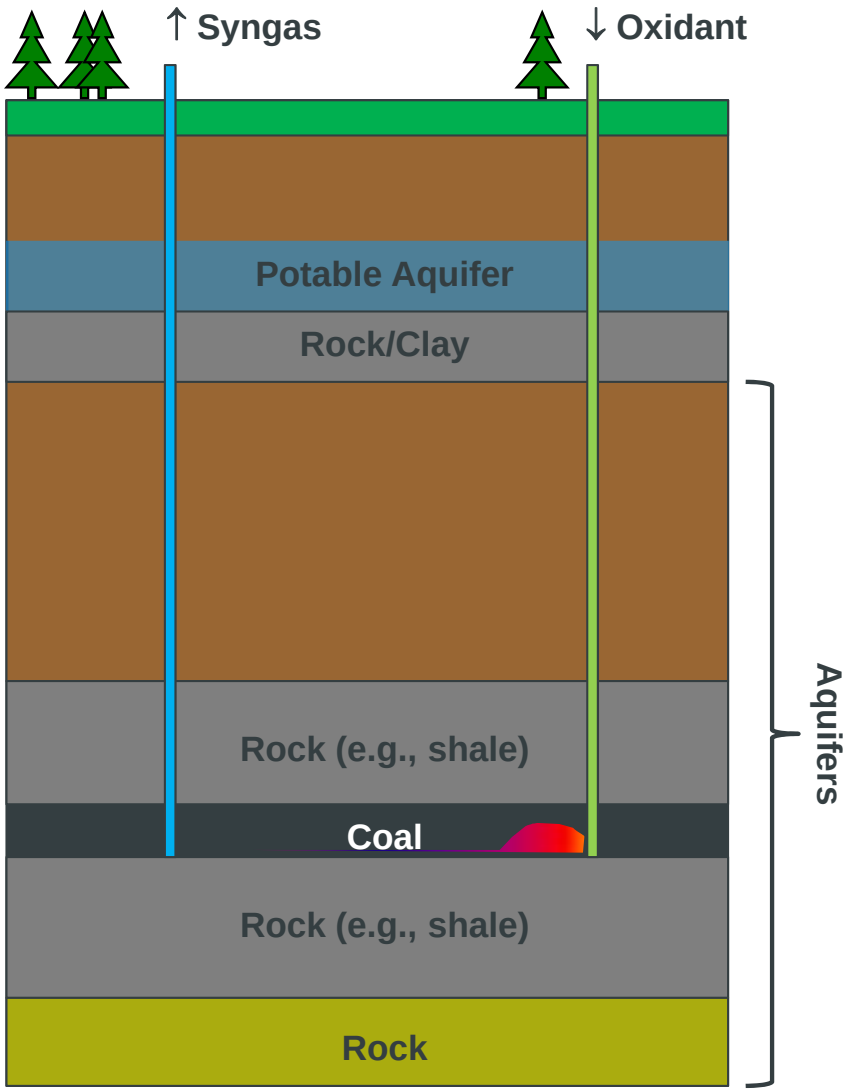


Image source: CATF

UCG potential environmental advantages

- Lower cost carbon capture and storage “CCS” on coal
  - UCG syngas is inexpensive
  - Efficient CO2 removal
    - Syngas can have high hydrogen content
    - Remove CO2 with conventional technology
  - Then fuel high-efficiency gas turbines with the low-CO2 syngas
- Low emissions of SO2, NOx, too
  - Like state-of-the-art IGCC
- Reduced solid waste/ash volumes
- No “mining”
  - Surface disruption is reduced
  - No tailings; no impoundments
- Can reduce potable water usage

Bloodwood Creek, November, 2008: View from the UCG reactor, past monitoring wells, to production facility

Image source: CATF

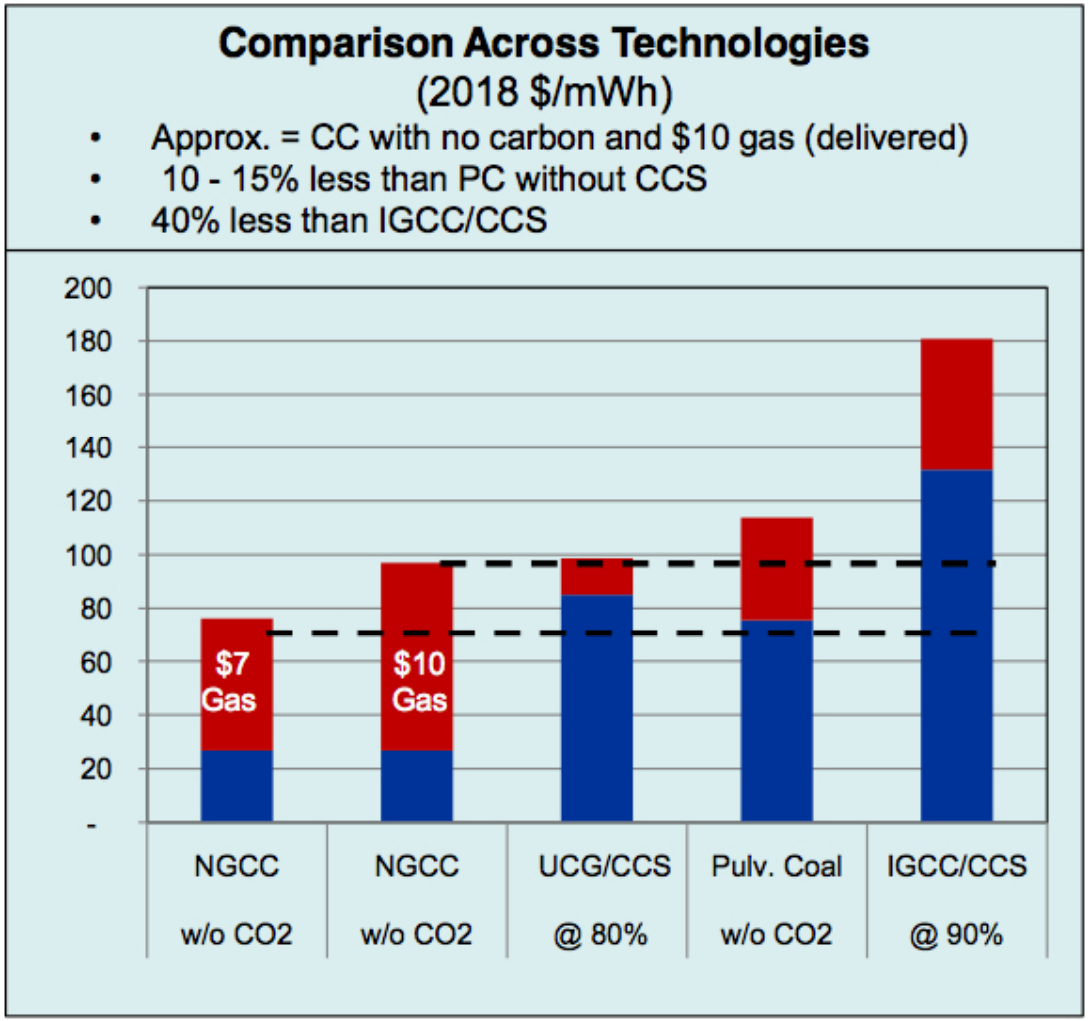
UCG experience is growing

- Commercial activity in former Soviet Union since Lenin's time
- Numerous small trials in US and Europe in 70s and 80s
  - A number of trials in Wyoming, including "Rocky Mountain 1" with DOE, EPRI, and others
  - Several trials created environmental problems due to poor siting and operation
- Five new projects making syngas since 2007
  - Eskom, South Africa, for power
  - ENN/XinAo Group, Inner Mongolia, for methanol
  - Carbon Energy, Australia, for ammonia and power, with CCS
  - Cougar Energy, Australia, for power
  - Swan Hills, Alberta, for power, with CCS

Source: UK DTI (2004), DOE/LLNL (2007 – draft), media reports, and other sources

UCG economics

- UCG could be a game-changer for CCS economics:
  - Raw syngas at $1 - $3 per MMBtu (GasTech, 2007; ENN, 2009)
  - 45.4% efficiency with combined cycle turbine (Aust.M&M.Assoc., 2002)
  - Manageable syngas cleanup/CO_2 removal costs
- UCG with CCS could be economically competitive with conventional coal and natural gas w/o CCS



Source: The NorthBridge Group for CATF. UCG estimate based on proprietary data supplied to NorthBridge by a private project developer. Costs include estimates of escalation in materials and other prices through 2018, and may differ from costs presented elsewhere.

CCS for existing coal units

- Post-combustion capture ("PCC") technology is available today
  - Example: A mineral processing operation in Trona, CA has been using PCC to remove about 800 tons of CO2 per day from coal fired utility boilers since 1978 (used for soda ash)
- Advancing the unit scale frontier remains critical
  - Basin Electric plans 120 MW in North Dakota
  - AEP plans 235 MW in West Virginia
  - Southern Company was planning 160 MW in Alabama
  - NRG plans 60 MW in Texas
- PCC cost appears competitive with other options
  - DOE 2007 estimate of $922/kW-retrofit capital cost
  - Capital cost escalation (e.g., steel prices) and make-up power costs must be considered, however

Data sources: CATF site visit; media reports; DOE/NETL, Carbon Dioxide Capture from Existing Coal-Fired Power Plants, 2007.

Challenges for PCC retrofits

- Need clean flue gas
  - Could have benefits for SO2 emissions (will need to be very low)
- Space:
  - EPRI estimates 6 acres for a 500 MW coal plant
  - Some space must be made available *within* existing plant systems
- Water:
  - Use will depend on plant cooling choices
  - Significant increases are possible (e.g., 10 gpm+ per MW retrofit)
- Loss in output:
  - 30% overall (potentially decreasing to ~20%)
- If loss in output were compensated by new intermittent renewables like wind power, the CCS retrofit could serve as back-up power for the renewables, as well as providing some existing transmission for those resources

Data sources: DOE/NETL, Carbon Dioxide Capture from Existing Coal-Fired Power Plants, 2007; G.T. Rochelle, Amine Scrubbing for CO2 Capture, 2009; EPRI, The Potential Growing Role of Post-Combustion CO2 Capture Retrofits in Early Commercial Applications of CCS to Coal-Fired Power Plants, 2009.

Recommended actions

- New NGCC
  - Include CCS in new projects
- Underground coal gasification
  - Form a Western-region utility study group for UCG
  - Evaluate potential for UCG syngas co-firing in existing natural gas assets, for development purposes
- PCC retrofits
  - Tri-State should expedite a 100 MWe PCC retrofit project on an existing coal unit
  - Study PCC retrofit and intermittent renewables synergies opportunities

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